BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Risk of Bends During Apollo Operations at 3.5 Psia Case 320

DATE: March 12, 1969

FROM: T. A. Bottomley

ABSTRACT

This memorandum assesses the risk that Apollo crewmen will suffer from bends as a result of being exposed to an oxygen/nitrogen mixture prior to decompression to 3.5 psia (e.g. EVA).

Based on the writer's interpretation of the data used in the referenced studies, the following conclusions were reached:

a) Not more than 5 out of 100 crewmen will experience bends symptoms in flight.

b) None of the cases will exceed Grade 1 (the lowest level) in severity and, therefore, will not be cause for mission abort.

c) Bends symptoms in 3 of the 5 cases will be relieved by recompression to nominal cabin pressure of 5 psia.

The following operational procedures are recommended to minimize the risk of bends during EVA:

a) Provide at least 4 hours preflight denitrogenation in 100% oxygen at a pressure of one atmosphere.

b) Schedule initial EVA not earlier than 10 hours from the start of preflight denitrogenation.

c) Provide a minimum of one hour denitrogenation in 100% oxygen at 5 psia prior to EVA.

(NASA-CR-106899) RISK OF BENDS DURING APOLLO OPERATIONS AT 3.5 PSIA (Bellcomm, Inc.) 9 p

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MEMORANDUM FOR FILE

During a recent Lunar Landing Training Vehicle (LLTV) accident briefing, Grumman Safety expressed concern about the possibility of bends resulting from astronaut exposure to low pressure (3.5 psia) after being in an 80/20 oxygen nitrogen (5 psia) atmosphere in the LM.[1]

In responding to this concern, the discussion in this report has been expanded to include CSM operations for the following reasons:

a) The crew will be exposed to the highest concentration of nitrogen (~30%) in the CM cabin prior to initial occupancy of the LM.[2]

b) The risk of bends is greatest during the boost and early phases of the mission and decreases as mission time increases.

c) The LM is pressurized by CM cabin gas plus oxygen makeup from CM supplies. Therefore, the nitrogen content of the LM atmosphere will always be equal to or less than that of the CM atmosphere at the time LM pressurization is initiated.

LM Cabin Atmosphere

At liftoff, the LM will contain air at ambient pressure. The LM Overhead Valve will be in "DUMP" so that, during the boost phase, the LM atmosphere will be vented overboard. The first LM pressurization will occur after transposition and docking. Assuming that the LM cabin is at vacuum and the CM cabin is at 5 psia and 70% oxygen, the final atmospheric composition in the two crew compartments will be not less than 84% oxygen. If the LM cabin has zero leakage, the LM atmospheric composition will remain essentially constant until crew entry. If the LM cabin leaks at the specification rate (0.2 lbs/hr), the LM cabin will be at near vacuum conditions prior to LOI. Assuming that the CM cabin contains 84% oxygen when the second LM pressurization is initiated, the final atmospheric composition in the LM/CM cabins will be about 91% oxygen.[2]

Bends Factors

In addition to the inert gas concentration, there are other important factors relating to the incidence and severity of bends which must be considered. These are:

a) Ratio of pressure change--significant if ratio of initial to final pressure exceeds 2:1.

b) Preflight period of pure oxygen denitrogenation--significant if less than four hours.

c) Energy level of activity--significant at high levels (>1200 Btu/hr).

d) Subject to subject variation; in particular, the ratio of body fat to lean body mass-significant with fat to lean ratios greater than 0.3:1.

The severity of bends has been graded as follows in the current literature:[3]

a) Grade 1 - intermittent or mild symptoms (tingling sensations and fleeting pains)

b) Grade 2 - moderate to severe symptoms not requiring abort (pain moderate but constant)

c) Grade 3 - severe symptoms requiring abort (pain intolerable, unable to work)

d) Grade 4 - severe decompression sickness

Bends Data

The most comprehensive set of experiments to assess bends risk during spaceflight was conducted by the Air Force in 1966. The collected data covered decompressions to 3.5 psia from 5 and 7 psia pure oxygen and mixed gas atmospheres (O_2/He and O_2/N_2) during a total of 388 subject exposures.[4]

Table 1 (attached) was prepared from these data to show the incidence and severity of bends for the atmospheric compositions and pressures used in Apollo.

As shown in Table 1, only three groups (designated A, B and C) were exposed to atmospheres typical to Apollo over all "mission" phases. However, all of the subjects were exposed to the same preflight and lift-off atmospheres and 55% of the total subject exposures were included in the "Initial EVA" phase.

Since the data gathered from the larger number of subjects were not compromised during these early phases by exposure to non-Apollo atmospheres (i.e. 7 psia O_2/N_2, 7 psia O_2/He and 5 psia O_2/He), they are included herein for evaluation purposes.

Persistence of Symptoms

The cases of bends noted in Table 1 cover both new occurrences and persistence of bends symptoms which occurred during an earlier phase. Based on information contained in the basic report, 55% of all Grade 1 cases persisted as Grade 1 and 10% progressed to Grade 2. No Grade 2 cases disappeared. One Grade 2 case persisted and the remainder progressed to Grade 3 (50%) or regressed to Grade 1 (50%).

Treatment of Symptoms

Of particular interest is that, of all cases which occurred at 3.5 psia following exposure to nitrogen mixtures, symptoms were relieved in 39% of the cases by recompression to pressures at or less than 5 psia. Relief was provided in more than half (55%) of the Grade 1 cases. Recompression to 7 psia (a capability provided in Apollo for testing the pressure suit) relieved symptoms of bends in 76% of the cases. These data are summarized in Table 2.

Apollo Risk

Referring again to Table 1, the high incidence of bends for the 51 subject exposures which include Group A is traceable to the limited period for denitrogenation (1.5 hours) and heavy exertion during the initial EVA. The table indicates persistence of Group A's symptoms throughout the remaining phases of the mission. These data show that the highest risk of bends in Apollo will occur early in the mission if preflight denitrogenation is not adequate (<4 hrs) and heavy work is required (e.g. early EVA, initial LM checkout, etc.) Grade 2 bends, if occurring early in the mission, may be considered cause for abort. Preflight denitrogenation becomes relatively unimportant about 12-16 hours after lift-off as the crew will equilibrate with the atmospheric environment in that time.

For purposes of assessing the bends risk during later Apollo mission phases the data for Groups B and C apply. The atmospheric exposures of these two groups provide upper and lower bounds (70/30 O_2/N_2 and 100% O_2) for predicting bends

incidence and severity in a gas mixture intermediate between the two (e.g. 80/20 O_2/N_2). Further, the data from groups B and C has not been compromised by persistence of symptoms from an earlier phase. Based on these data, and on an astronaut population having fat to lean body mass ratios not greater than 0.3:1, it is the writer's opinion that not more than 5 out of 100 crew members will experience symptoms of bends following decompression to 3.5 psia after exposure to a mixed gas composition containing not more than 20% N_2. The data also support a position that mission abort will not be required as none of the cases will exceed Grade 1 in severity. The basic reference indicates that 3 out of the 5 cases will recover with no treatment beyond recompression to the nominal cabin pressure of 5 psia.

Recommendations

Based on the foregoing discussion, the following operational procedures are recommended to minimize the risk of bends during Apollo missions:

a) Provide preflight denitrogenation (100% O_2 at 14.5 psia) of the crew for a period of not less than 4 hours.

b) Schedule planned extravehicular activity not earlier than 10 hours after the beginning of preflight denitrogenation.

c) As recommended in the basic reference, provide a minimum of one hour breathing pure oxygen at 5 psia, after crew members are exposed to a mixed gas environment, before EVA is attempted (4).

T. A. Bottomley

2033-TAB-sep

Attachments
Tables 1, 2

REFERENCES

1. NASA Memorandum to Apollo Program Director from Apollo Safety Director (C. McGuire) dated January 16, 1969.

2. LM Launch Atmosphere Alternatives - Case 320, Bellcomm Memorandum for File by R. D. Raymond dated July 10, 1968.

3. Berry, C. A. and Wayne, H. H. Disbarism, Grade 4 Chamber Reactions on Instances of Neuro Circulatory Collapse Occurring in the U. S. Air Force, 1950-1955. SAM-TDR-58-85, 1958.

4. McIver, R. G. Bends in Simulated Extravehicular Activity presented at Lectures in Aerospace Medicine, Brook's AFB, Texas 1967.

TABLE 1

INCIDENCE AND SEVERITY OF DECOMPRESSION SICKNESS (BENDS)

Mission Phase	Phase Duration	Group (includes)	Atmosphere Comp.	Atmosphere Press.	Total Time*	Total No. Subject Runs	Incidence No.	Incidence %	Severity Grade 1	Severity Grade 2	Severity Grade 3
Preflight	--	(A)	100% O_2	14.7psia	1.5 hrs	52	--	---	-	-	-
		(B&C)	100% O_2	14.7psia	4.0	336	--	---	-	-	-
Lift-off & Orbit	2.5 hrs	(A)	100% O_2	5 psia	4.0	52	5	9.6	1	3	1ϕ
		(B&C)	100% O_2	5 psia	6.5	336	1	0.3	1	0	0
Initial EVA (Heavy Work)**	0.25	(A)	100% O_2	3.5psia	4.25	51	12	23.6	7	5	0
			100% O_2	3.5psia	6.75	160	11	6.9	9	2	0
Cabin Atmosphere Exposure	4	A	100% O_2	5 psia	8.25	20	7	35.0	2	4	1ϕ
		B	100% O_2	5 psia	10.75	28	0	0	0	0	0
		C	70/30 O_2/N_2	5 psia	10.75	36	0	0	0	0	0
Final EVA (Mod. Work)***	2	A	100% O_2	3.5psia	10.25	19	10	51.7	4	2	4
		B	100% O_2	3.5psia	13.00	28	1	3.6	0	1	0
		C	100% O_2	3.5psia	13.00	36	3	8.3	3	0	0

( ) Indicates the group is included in the total number of subject exposures.

* Time to end of mission phase after start of denitrogenation

** 5 deep knee bends and 5 pushups every 5 minutes.

*** 5 deep knee bends and 5 pushups every 15 minutes.

ϕ Subject removed from experiment

From Reference 4

TABLE II

3.5 Psia Bends Cases Relieved

by Recompression - Nitrogen[4]

Grade	Recompression Pressure		
	<5 psia	5-7 psia	>7 psia
1	12	9	1
2	5	5	5
3	1	3	5

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